End-to-end quality of service for large distributed storage

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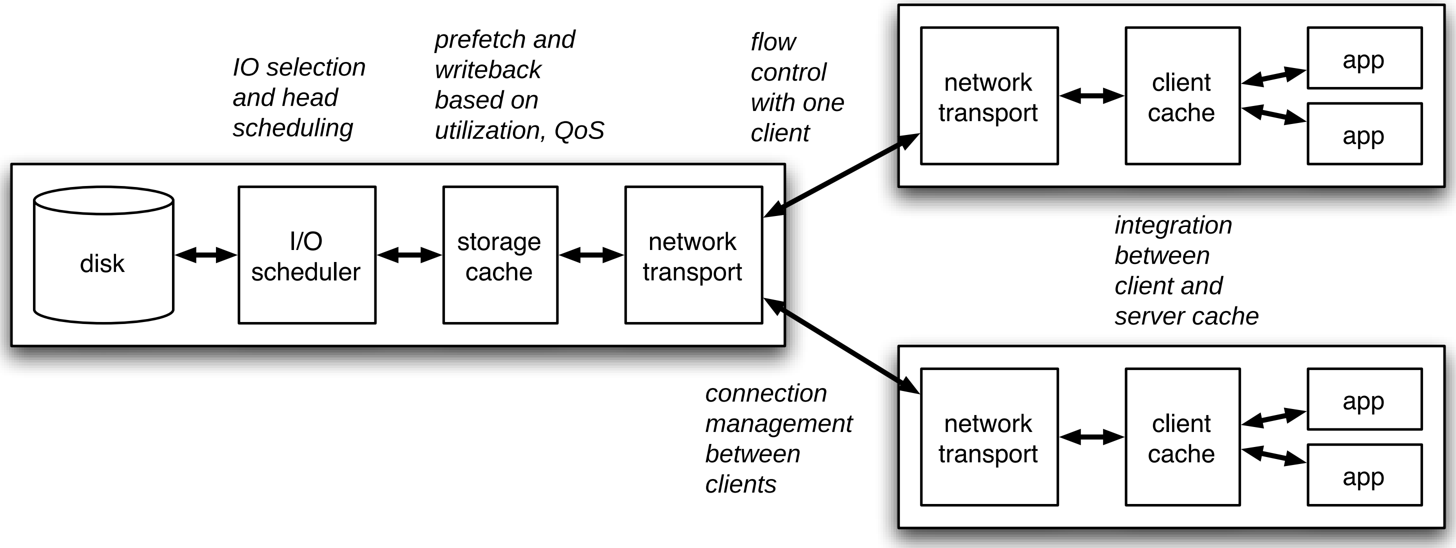
Project overview

- Collaboration between UCSC / IBM Almaden
  - UCSC: Scott Brandt, Carlos Maltzahn
  - IBM: Richard Golding, Theodore Wong
  - 3 years / $1,000,000
- Goal: Improve end-to-end performance management in large clustered storage
  - From client, through server, to disk
  - Manage performance
  - Isolate traffic
  - Provide high performance

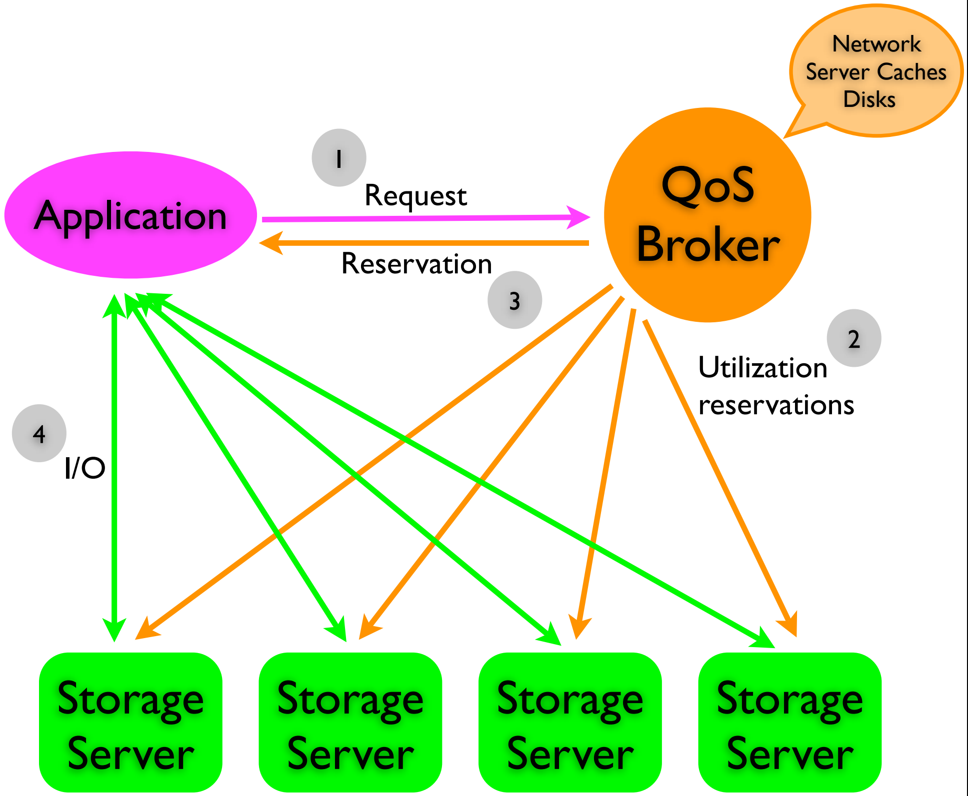
Stages in the I/O path



1. Disk traffic
2. Management of server cache
3. Flow control across network
    - within one client's session; between clients
4. Management of client cache

System architecture

- Applications request reservation from broker
    - Specify workload: throughput, read/write ratio, burstiness, etc.
- Broker does admission control
    - Requirements are translated to utilization
    - Utilizations are summed to see if they are feasible
    - Once admitted, I/O streams are guaranteed (subject to workload adherence)
- Disk, cache, network controllers maintain guarantees



Fahrrad: Efficient QoS-aware Disk Scheduling

- Control of application resource reservation and usage *at the disk level*

- Goals:
  - Mixed hard, soft, and non-real-time workloads
  - Arbitrary granularity of reservations
  - Complete isolation of workloads
  - Excellent I/O performance

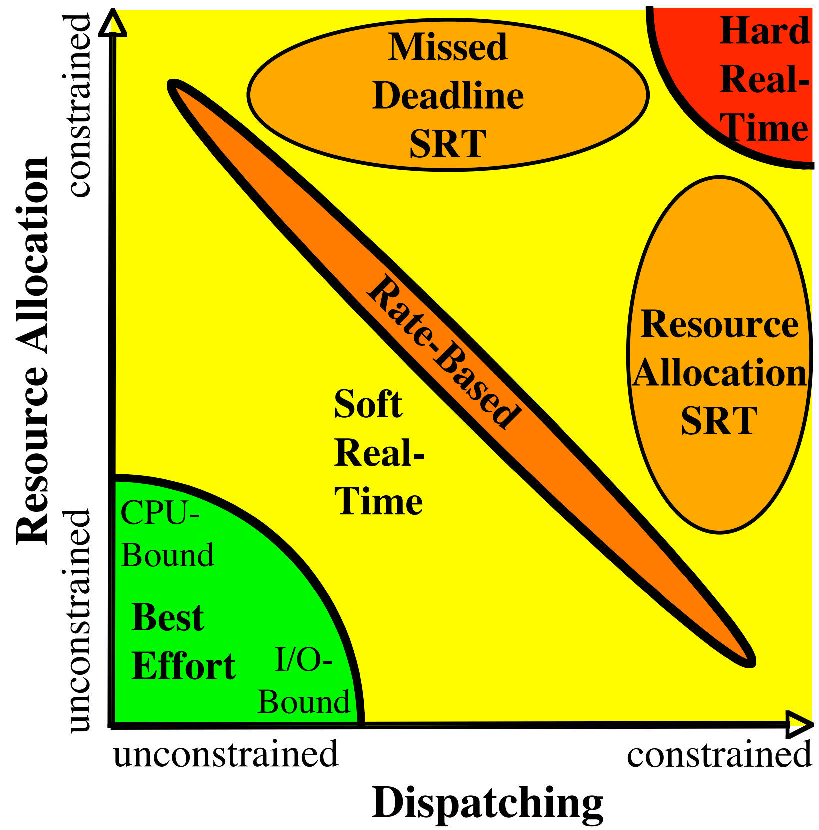
Key observation

- Scheduling consists of two distinct questions

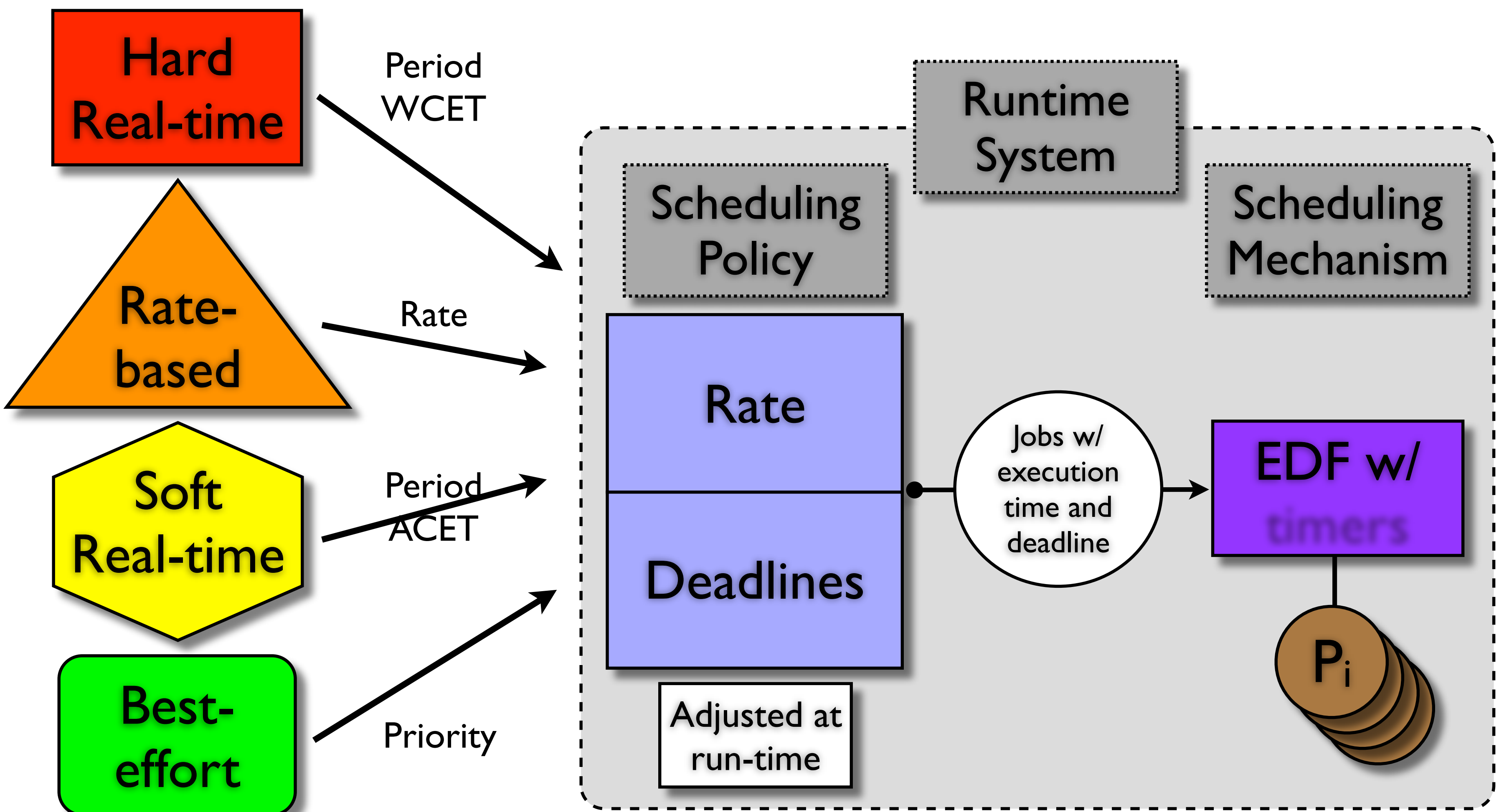
  Resource allocation: *How much* resources to allocate to each process

  Dispatching: *When* to give each process the resources it has been allocated

- Most schedulers integrate their management
- Separating them is powerful!



RBED RAD-based CPU scheduler



Utilization-based disk reservations

- Throughput reservations
  - Assume worst-case behavior
  - Allows reservation of a tiny fraction of actual throughput
- Utilization reservations
  - Easy to make, account for, and guarantee
  - Embed application workload information
  - Avoid the need for worst-case assumptions
- Workload knowledge + utilization reservation + isolation = throughput guarantee

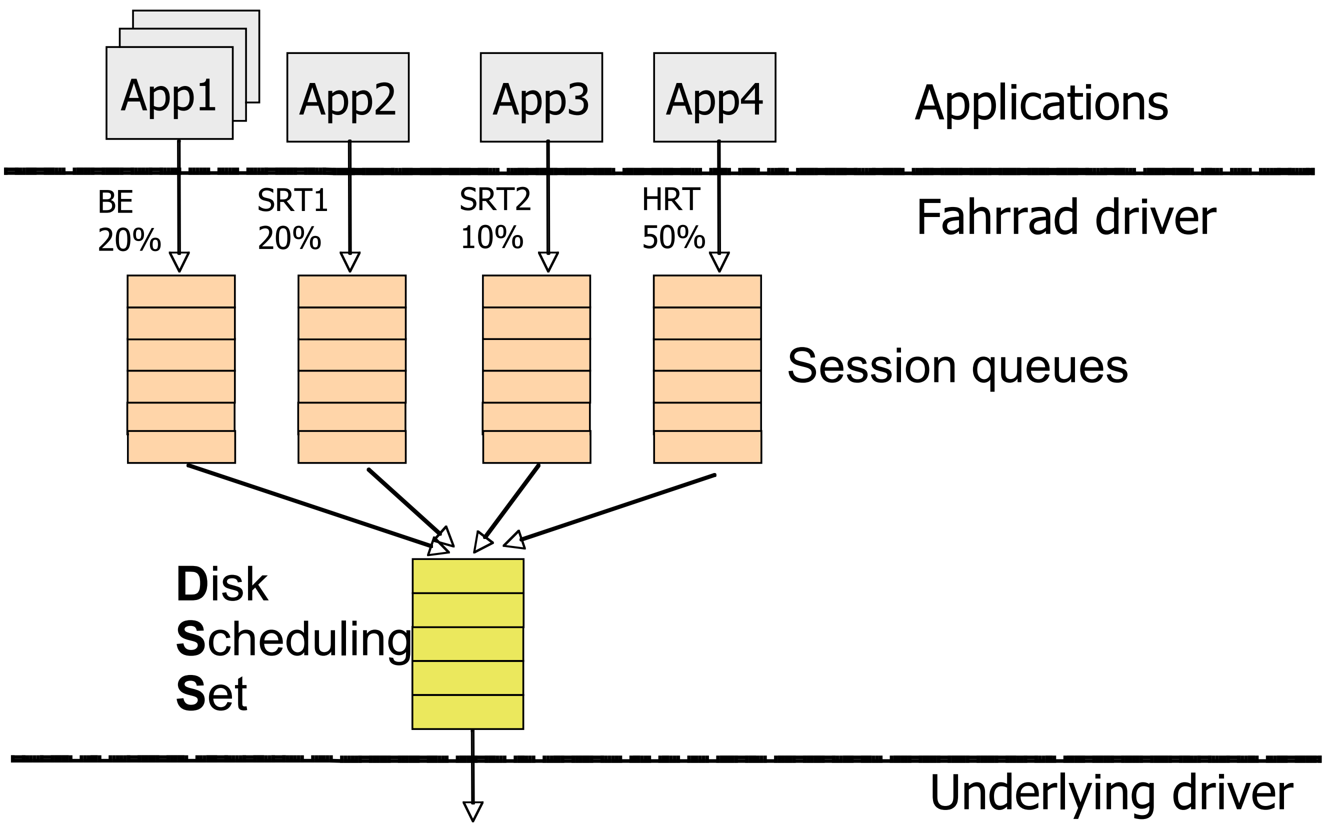
Applying RAD to disk I/O

- Reservations based on disk time utilization
  - Rate = utilization
  - Deadlines = times at which actual utilization must equal reserved utilization (= latency bound)
- Need to be able to reorder requests for performance
  - All requests that can be handled without jeopardizing deadlines are put into a reordering set
- Cannot ignore "context switches" (seeks)

Fahrrad: RAD-based I/O scheduling

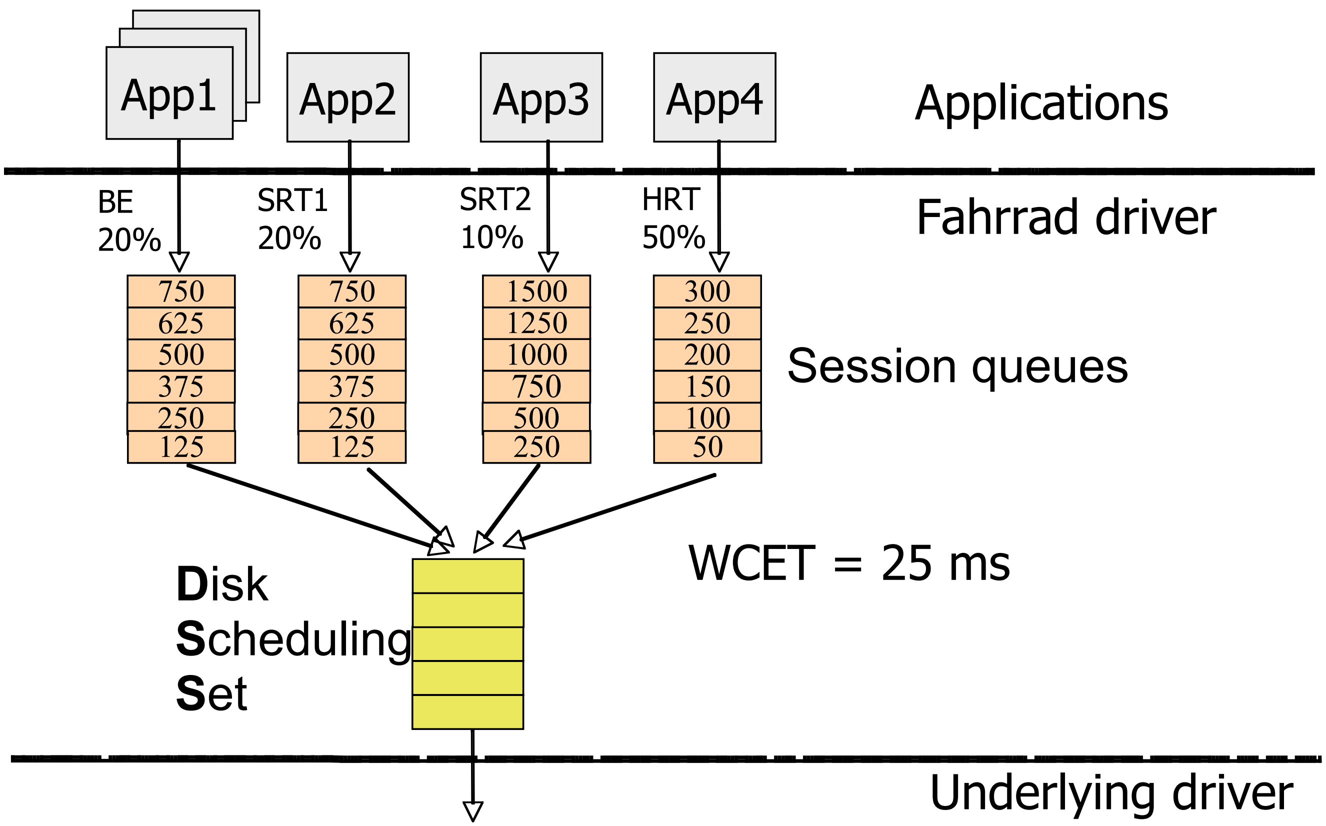
1. Utilization-based reservation, with deadlines
   - e.g., 50% of the disk every second, 10% every hour, etc.
2. Requests put into queues
   - Each queue has a rate and deadlines
3. Micro-deadlines assigned to requests based on target rate and worst-case assumptions
4. Requests released to Disk Scheduling Set (DSS) based on micro-deadline
5. Requests scheduled for service from DSS
6. Micro-deadlines updated based on actual service times

Fahrrad architecture



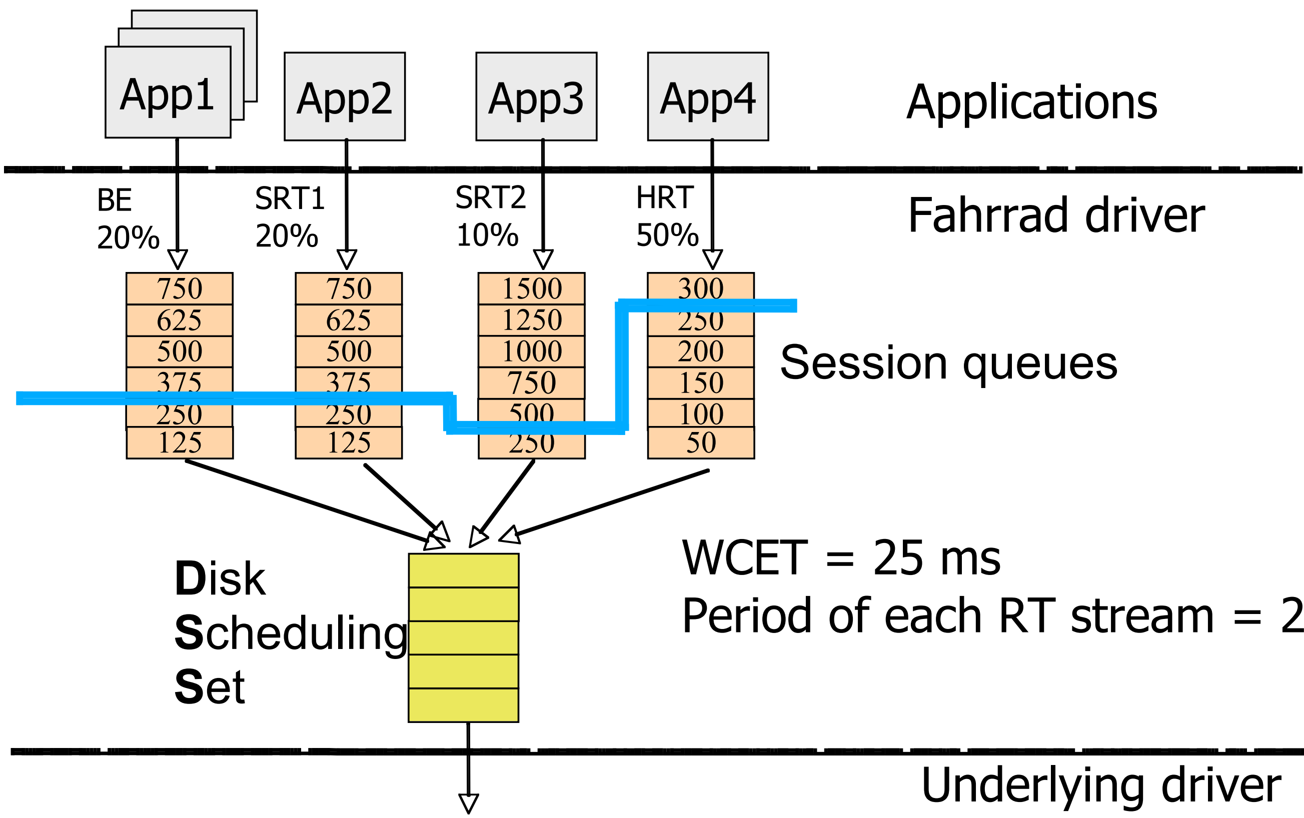
Guaranteeing deadlines

µdeadlines assigned to each request: $d_i = d_{i-1} + WCET / U$



Release to DSS

Requests with μ-deadline up to horizon (earliest deadline) move to DSS

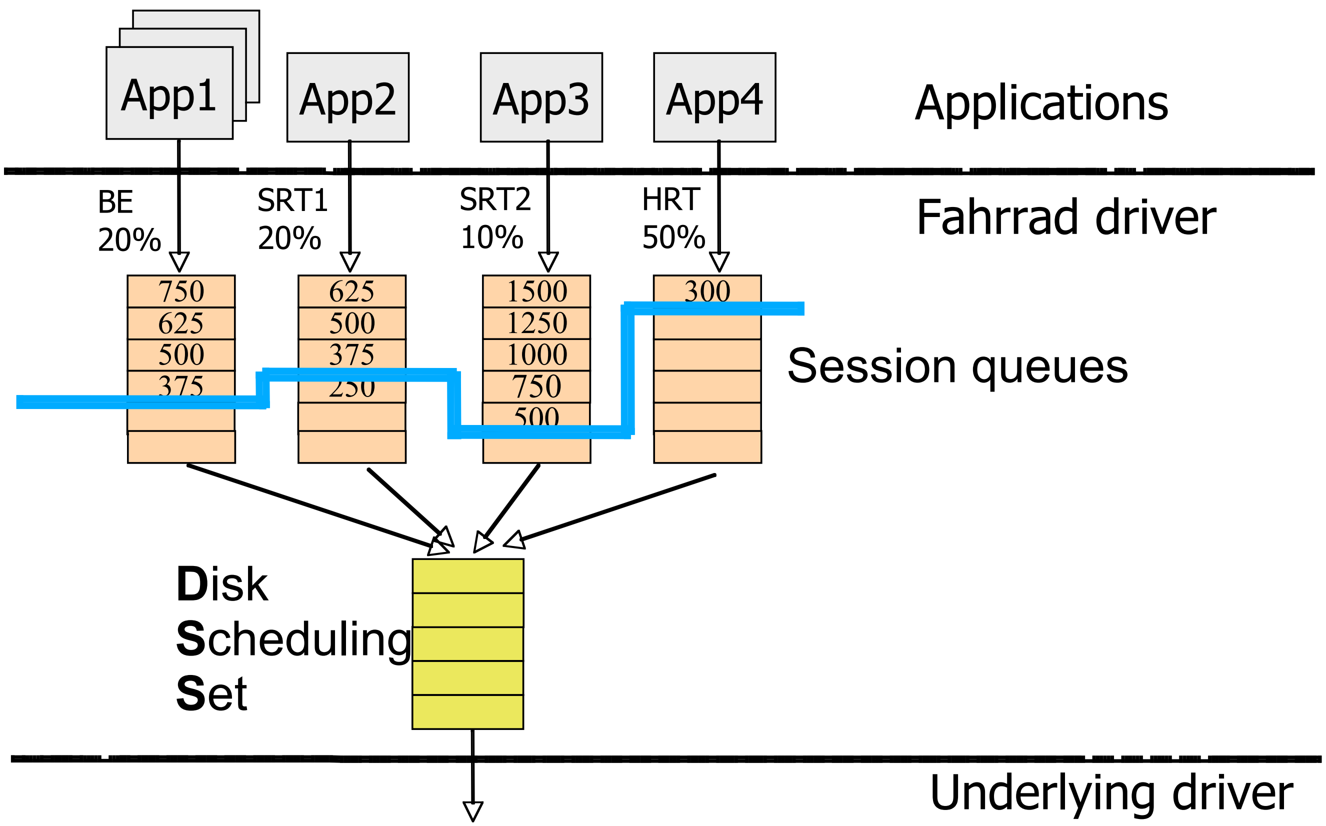


WCET = 25 ms

Period of each RT stream = 250 ms

Guaranteeing utilization

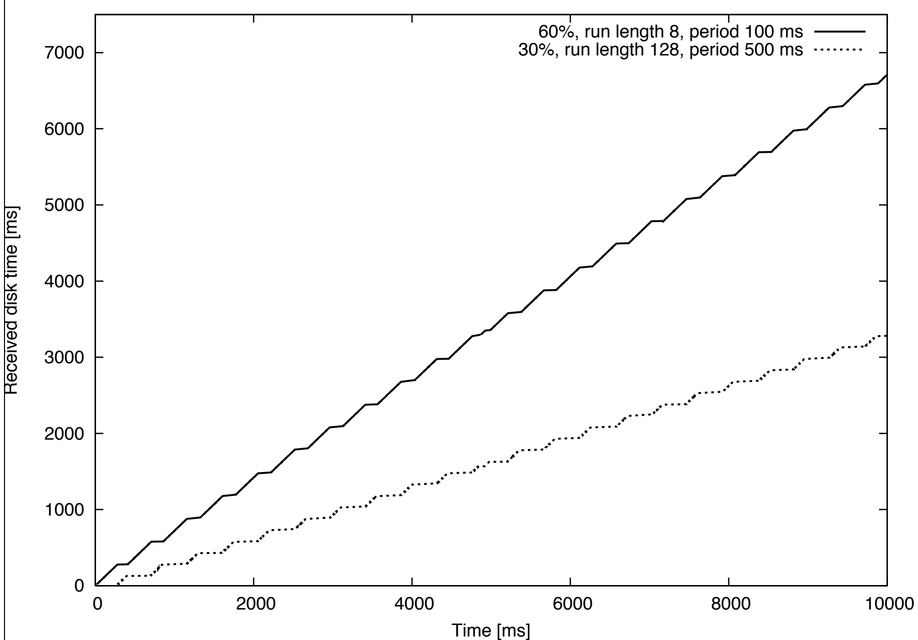
Guarantee reserved utilization by shifting μ-deadlines



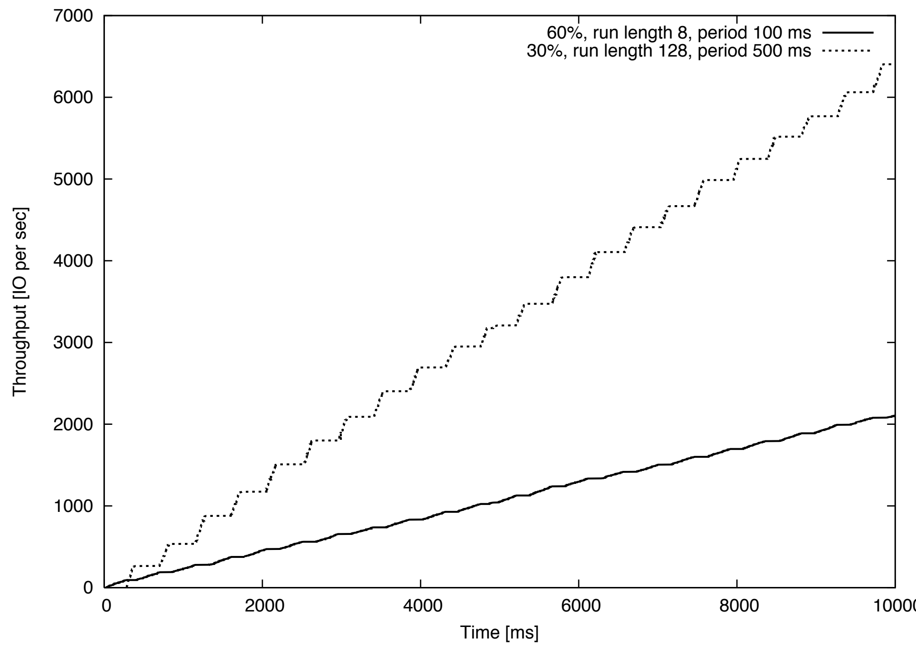
A few details

- DSS scheduling
  - C-SCAN, SPTF, **EDF**
- Managing burstiness
  - *Slots*—reserve utilization until request arrives
    - Unused slots are allocated to other streams
  - *Slot swapping*—aggregate requests in DSS by swapping slots
    - Increases sequentiality of DSS
    - Increases isolation and performance
- Isolation—accounting for overheads
  - Each stream charged for its seeks
  - Each streams charged 2 seeks per deadline

Fahrrad works



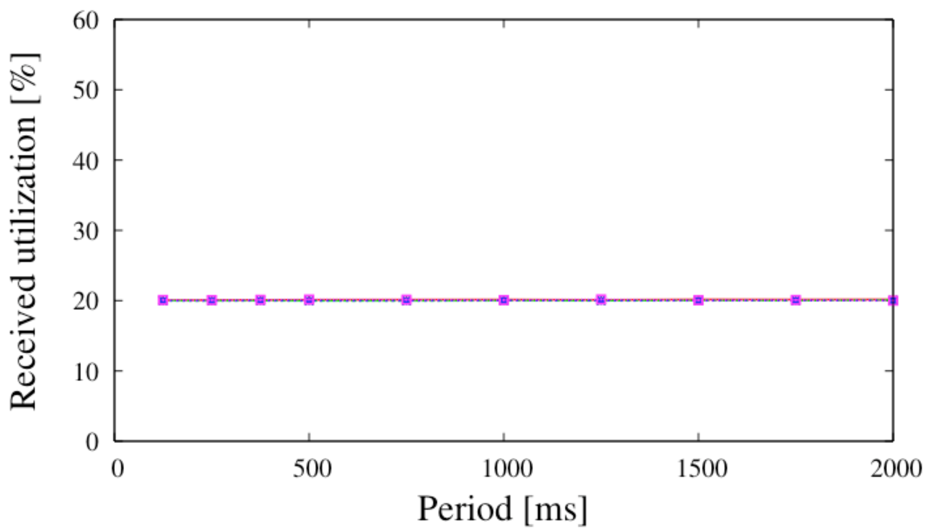
Utilization



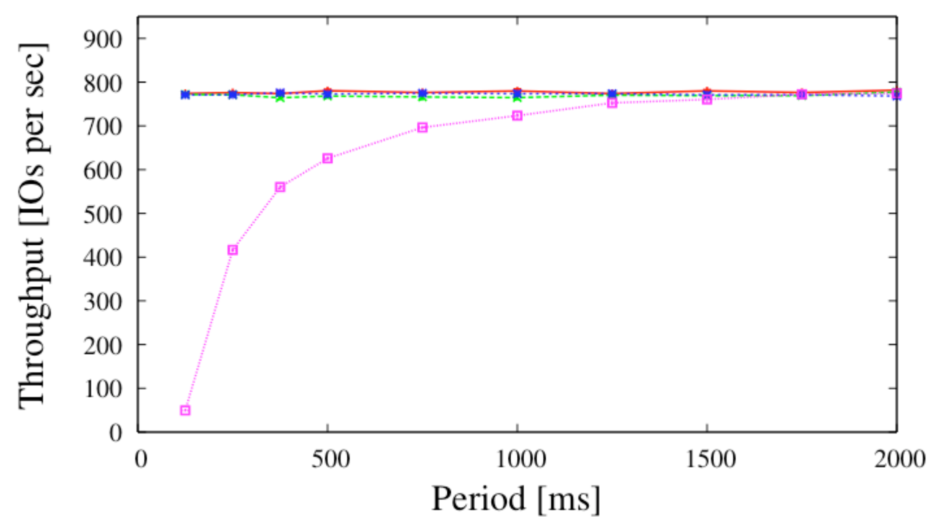
Throughput

Isolation between request streams

Utilization



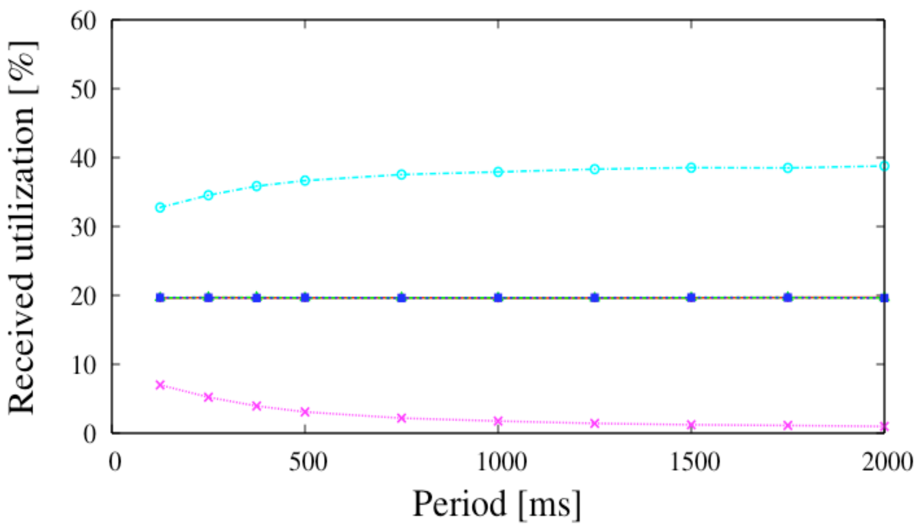
Throughput



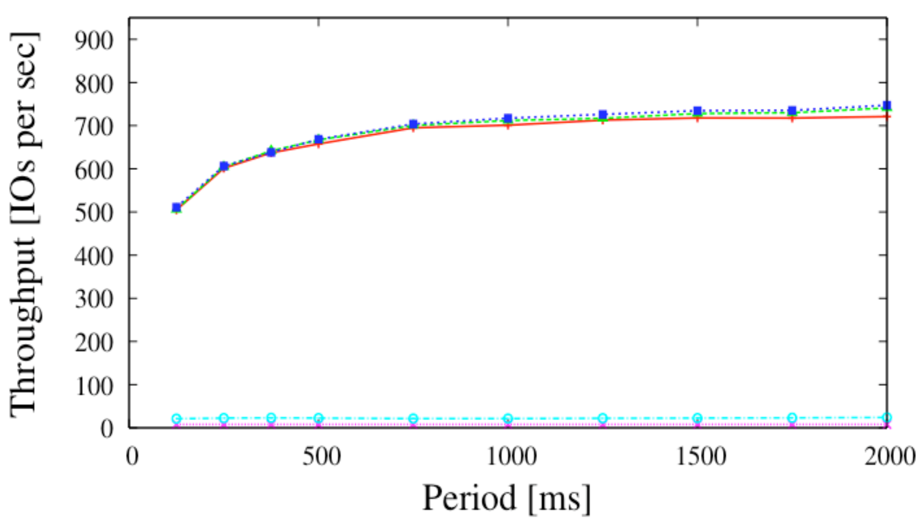
- Utilization and throughput of 4 I/O streams as period of stream 4 changes (sequential streams w/long queues)
- Rate: 20%
- Deadlines
  - Streams 1-3: 2s
  - Stream 4: varies from 125 ms to 2 s

HRT and BE (slack goes to BE)

Utilization

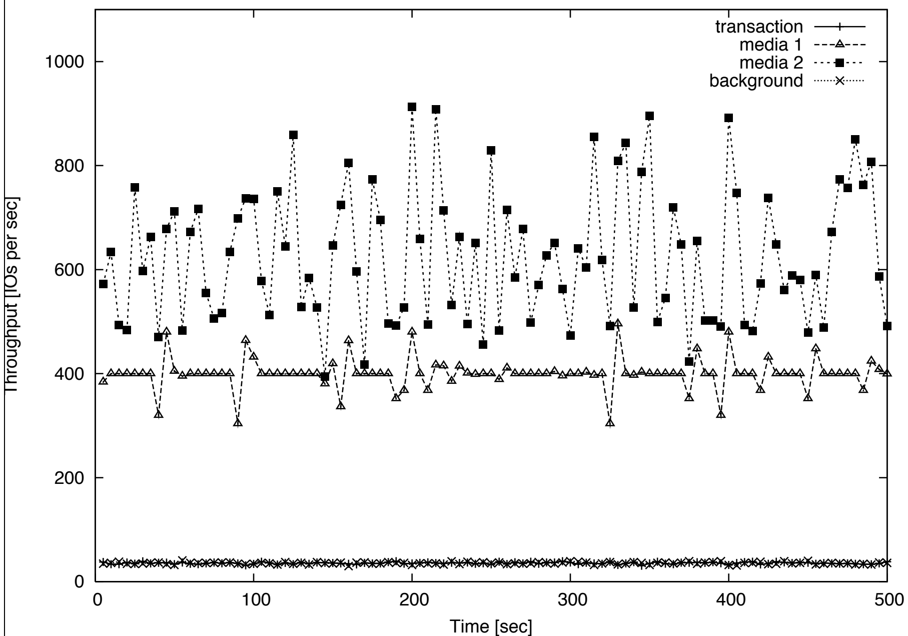


Throughput

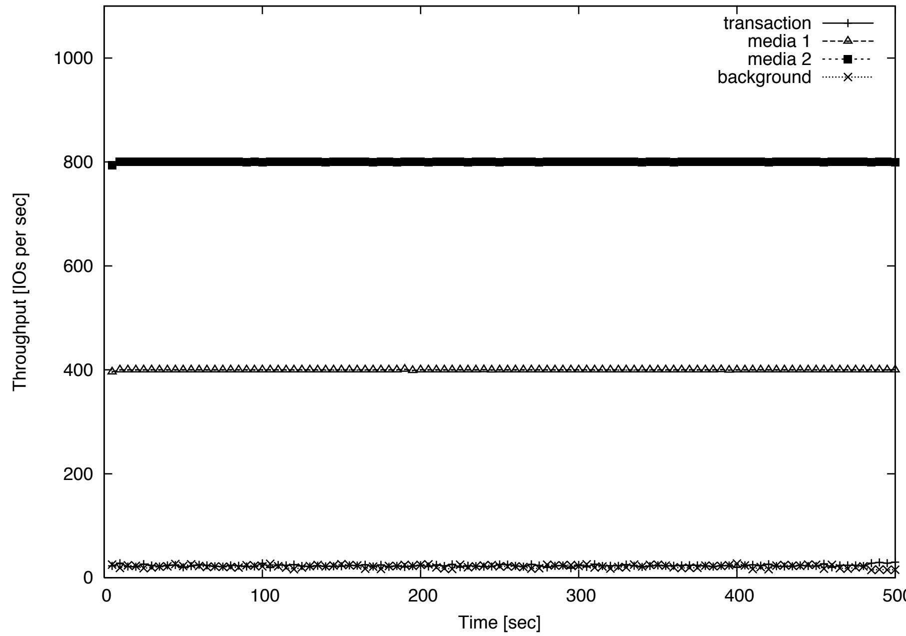


- Utilization and throughput of I/O streams as period of stream 4 changes
- Rate: 20%
- Deadlines
  - Sequential SRT streams & random BE stream: 2s
  - HRT: varies from 125 ms to 2 s

Performance vs. Linux



Linux



Fahrrad

Disk scheduling conclusions

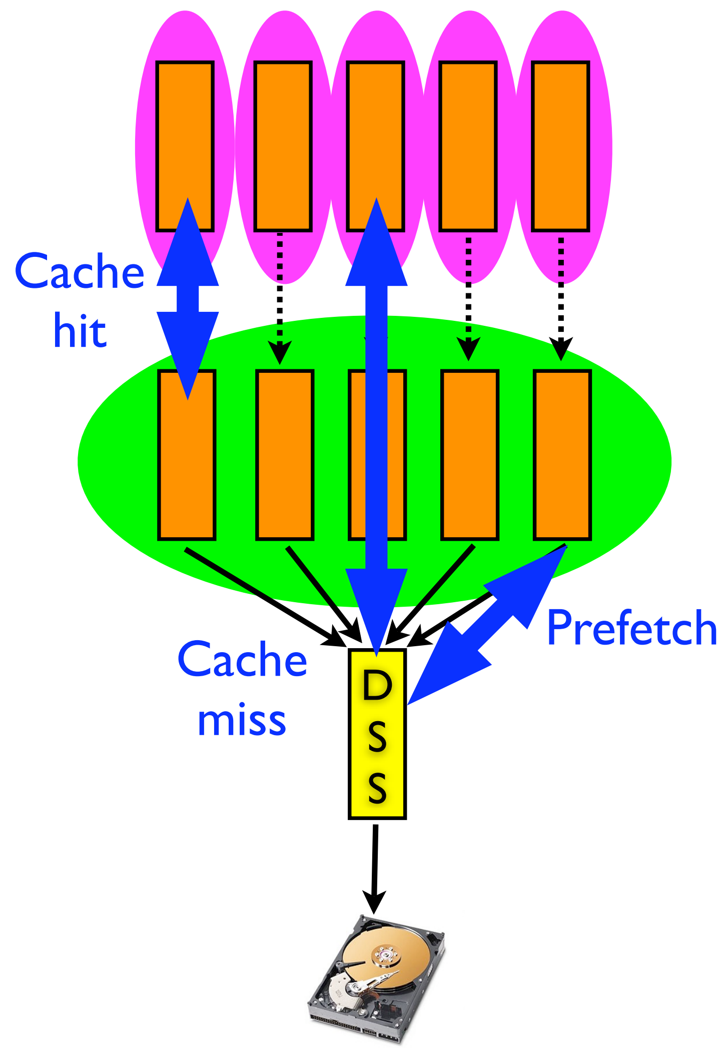
- Fahrrad provides
  - Integrated hard real-time, soft real-time, and best-effort service
  - Arbitrary (nearly) reservation granularity
  - Excellent isolation between processes
  - Excellent performance

Server cache management

- Server caching isolates disk from application behavior
  - Buffering smooths workload
  - Isolates disk from application period
    - Disk deadlines are buffer full times
  - Translates between time to space (and back)
  - Aside: best-case for disk = worst-cast for cache

Server cache management

- Reads and writes are handled differently
- Read cases
  1. *Cache hit*: creates slack
  2. *Cache miss*: sent to disk
  3. *Prefetch*: uses slack to increase efficiency
- NV cache⇒writes can be delayed indefinitely
- In general: need at least 3 periods of server cache



Network management

- Moving data from client cache to server cache
- Network QoS is well-explored
  - Currently examining existing solutions
- Cases
  1. One client/server route: O(1)
  2. One client/server route with arbitrary application placement: O(n)
  3. Many client/server routes
     - w/trunking: polynomial with linear programming: O(n)?
     - w/out trunking: NP-complete?

Client cache management

- Holds application data for transfer to server
- Further isolates application from disk
  - Further reduces burstiness
  - Further addresses independence of periods
- Coordinates with network and server cache

Spinoff: virtual disks

- Virtual disks—complete isolation of disk functionality
  - Capacity isolation
  - Temporal isolation
  - Performance isolation
- LUNs provide capacity isolation
- Fahrrad provides temporal and performance isolation

Conclusions

- Excellent progress (< 1 year along)
- Disk scheduling: Fahrrad
- Server cache: In progress
- Networking: Preliminary investigation
- Client cache: TBD
- Lots of industry interest: IBM, NetApp, VMware, SAP, NICTA/OK Labs, ...
- Pursuing DARPA follow-on building on end-to-end QoS